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BIM-based automated water supply design for high-rise in compliance with Vietnamese standards

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KEYWORDS

Automatic Pipe sizing
Domestic plumbing system design
Building information modelling (BIM)
Automatization
Visual Basic for Applications (VBA)

ABSTRACT

Designing modern water supply systems is a complex process involving precise flow rate determination, pipe sizing, and head loss analysis. Currently, these tasks remain largely manual; existing tools lack full automation, leading to higher costs and technical errors. This study develops an integrated BIM-based solution that fully automates hydraulic calculations and simultaneously updates the building information model, thereby increasing design efficiency and enhancing documentation quality. By leveraging Dynamo-based automation to overcome the limitations of Revit's native 'Pipe Sizing' and enforce compliance with Vietnamese standards (specifically TCVN 4513:1988), the tool significantly streamlines the hydraulic design process. Beyond basic sizing, it automatically identifies the most hydraulically adverse pipe run to accurately determine critical system pressure. This comprehensive workflow reduces manual iteration and ensures calculation accuracy and model consistency throughout the project lifecycle.

1. Introduction

Driven by the construction industry's digital transformation, Building Information Modeling (BIM) has established itself as the pivotal framework for optimizing design, construction, and facility management [1, 2]. In MEP engineering, particularly for water supply systems, BIM implementation extends beyond 3D visualization to automate hydraulic calculations, optimize system design, and ensure adherence to technical codes [3, 4]. In Vietnam, water supply system design remains predominantly reliant on conventional, experience-based calculations. However, this approach reveals significant limitations in large-scale or complex developments, causing extended design timelines, poor error traceability, and a lack of standardization. Crucially, manual methods often struggle to ensure rigorous compliance with Vietnamese Standards (TCVN) [5, 6].

Autodesk Revit has become a staple of modern MEP design, providing a powerful platform that simplifies model creation and streamlines model management [7]. However, Revit's native tools fall short of fully automating water supply design, particularly when compliance with TCVN is required. It lacks robust support for critical tasks like flow determination, pipe sizing, and pressure estimation. This forces designers into a fragmented workflow where data is calculated externally and manually re-entered, significantly undercutting the efficiency of the BIM process [8].

The International Plumbing Code (IPC) [9] determines pipe sizing primarily through plumbing fixture units (FU) and tabulated conversions. TCVN 4513 [10] mandates a more intricate approach. Under this standard, pipeline design flow rates are calculated by determining the total fixture unit values of a given pipe section, followed by the verification of hydraulic performance criteria, including flow velocity and pressure loss. Consequently, the complexity of the TCVN framework creates a substantial computational burden that is difficult to automate within standard BIM environments.

Existing studies on BIM-based automation primarily focus on leveraging visual programming tools to support parametric design and model generation, facilitating preliminary evaluation during the early project stages [11, 12]. While effective in reducing repetitive operations and improving modeling efficiency, these approaches prioritize geometric modeling and model organization, often overlooking the automation of critical engineering design workflows [11, 13]. Regarding water supply systems, most domestic studies have not fully implemented automated hydraulic calculations or leveraged Revit's integrated tools. Consequently, computed outputs do not comprehensively reflect TCVN requirements and lack direct synchronization with the BIM model. In practice, such calculations remain largely indicative, relying on generic software algorithms that limit compliance with detailed provisions and constrain scalability for projects with specific design criteria.

Furthermore, several studies have developed approaches for automated pipe routing, MEP system configuration, and in-model clash detection, utilizing rule-based systems or algorithm-driven modeling techniques [14, 15]. However, these methods exhibit limited flexibility and adaptability in complex projects, particularly where site-specific conditions or local code requirements demand customization. Alternatively, research into automated 2D-to-BIM conversion offers another path. Despite its high automation potential, this approach is inherently fragile; it depends entirely on the quality of input CAD data, leading to frequent errors when drawings do not strictly adhere to standardized formats [16, 17].

Prior research has largely emphasized automated model

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generation, pipe routing, and generalized computational assistance, yet there remains a lack of integrated frameworks capable of fully automating TCVN-compliant hydraulic calculations for water supply systems and synchronizing the outputs directly with BIM models. In response, this study introduces an integrated approach combining Revit, Dynamo, and Excel VBA to automate the complete hydraulic calculation workflow in accordance with TCVN 4513:1988 [10]. The methodology covers design flow estimation, pipe sizing, flow velocity assessment, and pressure loss evaluation, with calculated results automatically embedded into the Revit model. The proposed framework improves computational reliability, minimizes manual operations, and contributes to the standardization of water supply system design within BIM-based practice.

2. Methodology

2.1. Scope and design compliance

The program is developed to support the hydraulic design process of domestic water supply systems in accordance with TCVN 4513:1988 [10]. The primary objective of this tool is to assist engineers in determining appropriate pipe diameters, design flow rates, and adequate pressure distribution within building water supply networks in a rapid and efficient manner, while greatly improving overall design consistency. The program only considers sanitary fixtures listed in the standard, as well as devices with similar fixture units or flow rates, thereby ensuring compatibility with the prescribed calculation methodology.

To perform the calculations, the program requires input parameters that reflect actual building conditions, including pipe lengths, fixture locations, and floor elevations. In addition, the minimum required pressure at each fixture is incorporated as a verification criterion to assess whether the system meets performance requirements after calculation. Compliance with TCVN 4513:1988 [10] is ensured through the implementation of the fundamental design principles defined in the standard.

2.2. Integrated BIM-based framework and computational workflow

This study develops an integrated framework that leverages BIM data to drive hydraulic calculations via Excel VBA, automate the design process, and dynamically update results within Revit model. Built using Dynamo and Excel VBA, this framework is integrated as a functional add-in within the Revit environment. As presented in Figure 1, the general workflow comprises six principal stages: model development in Revit; extraction of model parameters to Excel; execution of hydraulic calculations using VBA; reintegration of computed outputs into the BIM model; segmentation of calculation sections with iterative design adjustment; and determination of the most hydraulically unfavorable pipeline. Once the initial BIM model is established, the subsequent workflow operates automatically.

Within this framework, Revit serves as the core BIM platform where the piping network is modeled as parametric elements capable of storing necessary geometric and technical data, including pipe length, elevation, connectivity attributes, and required fixture unit values. Post-computation, the optimized parameters are automatically written back into the Revit model, ensuring consistency, accuracy, and total synchronization between the design representation and the analytical results while maintaining high data integrity.

Dynamo, a visual programming interface embedded within Revit, operates as the central data processing unit of the proposed framework [18]. It establishes a bidirectional data exchange mechanism between Revit and Excel, automatically extracting relevant model parameters and transmitting them to Excel for hydraulic computation. Following the calculation in compliance with TCVN, Dynamo reintegrates the computed outputs into the Revit model, performing automated pipe segmentation and assigning appropriate pipe diameters to each segment in accordance with the finalized design criteria.

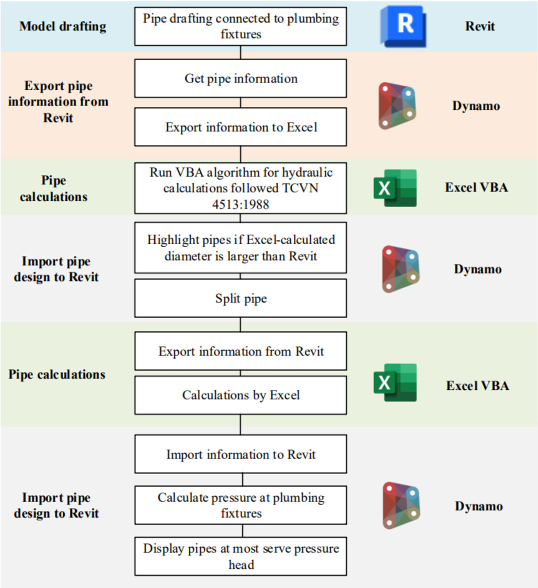

Figure 1. The general framework workflow.

Within Excel, VBA functions as the dedicated hydraulic calculation module. The detailed hydraulic equations prescribed by TCVN 4513:1988 are encoded into structured programming modules. Upon receiving input data from Dynamo, VBA executes iterative and conditional algorithms to compute design discharge, flow velocity, pressure loss, and optimal pipe sizing. The processed results are subsequently exported back to Dynamo to complete synchronization with the BIM model. The VBA-based approach provides enhanced computational transparency and step-by-step verification of TCVN compliance. Compared with approaches that rely exclusively on Dynamo or entirely embedded Revit scripting, the proposed architecture offers superior control over the calculation process and improved traceability of TCVN-based hydraulic verification.

3. Results and discussions

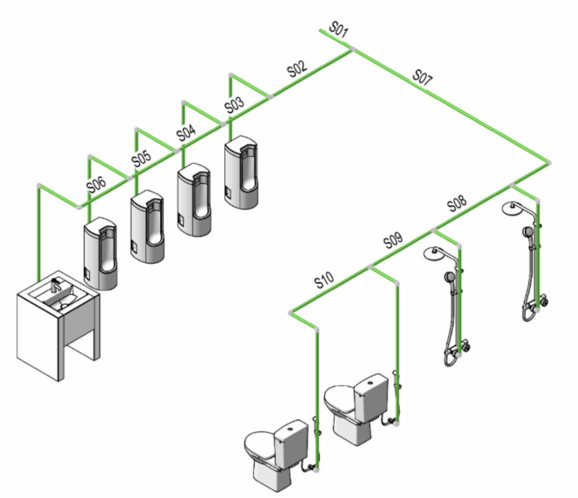

Figure 2. Representative an office restroom water supply model.

To evaluate the effectiveness of the proposed framework, the water supply system of a representative office building restroom (Figure 2) was analyzed using two approaches: (1) the conventional method and (2) the automated method employing the integrated Revit-Dynamo-Excel framework developed in this study. Under the conventional approach, design flow rates, pressure losses, pipe diameters, and velocity verifications were performed manually. This iterative procedure relies heavily on the designer's experience, particularly in complex systems with numerous branches or plumbing fixtures. In contrast, the proposed framework automatically extracts BIM data, executes hydraulic computations, and updates the Revit model without manual intervention. The results are compared in the following tables to evaluate accuracy, execution time, and the reduction in manual involvement. Figure 2 illustrates the water supply layout of the representative office restroom. Calculation nodes are labeled from S01 to S10, where pipe diameters vary along the network. The model includes the following sanitary fixtures: 2 water closets, 2 showers, 1 wash basin, and 4 urinals.

Table 1 presents the plumbing fixture unit values of the sanitary appliances shown in Figure 2 in accordance with TCVN 4513:1998 [10].

Table 1. Plumbing fixture units (FU).

Fixture Name	Abbreviation	FU
Lavabo	LA	0.33
Water Closet with Tank	WC	0.5
Shower	SH	0.67
Urinal with automatic flush	UR	1

3.1. *Conventional approach*

According to TCVN 4513:1988 [10], the design water supply flow rate, flow velocity, hydraulic gradient, and head loss along each pipe segment of the office building are determined using Equations (1) through (4).

$$Q_{tt} = 0.2 \times \alpha \times \sqrt{\sum N} \qquad [1]$$

$$V = \frac{4Q}{\pi D^2} (m/s) \qquad [2]$$

$$i = 0.000685 \times \frac{V^{1.774}}{D^{1.226}} \qquad [3]$$

$$h_{dd} = i \times L \ (m) \qquad [4]$$

where Q_{tt} is the design flow rate (L/s), N is the total plumbing fixture units, α is the building usage coefficient, Vis the flow velocity (m/s), D is pipe diameter (m), i is hydraulic gradient, L is the pipe length (m), and h_{dd} is majoi head loss (m).

Table 2 presents the hydraulic calculation results for the water supply system layout shown in Figure 2, where *DN* denotes the nominal diameter of the piping segments.

Table 2. Design results using the conventional approach.

Section	*L (m)*	*N*	*Q_{tt} (l/s)*	*DN (mm)*	*ID (mm)*	*V (m/s)*	*i*	*h_{dd} (m)*
S01	0.47	6.67	0.77	32	26.2	1.44	0.11	0.05
S02	1.2	4.33	0.62	32	26.2	1.16	0.08	0.09
S03	0.66	3.33	0.55	25	19.4	1.85	0.26	0.17
S04	0.65	2.33	0.46	25	19.4	1.55	0.19	0.12
S05	0.66	1.33	0.35	20	15.4	1.86	0.34	0.23
S06	2.65	0.33	0.17	20	15.4	0.93	0.10	0.26
S07	3.4	2.34	0.46	25	19.4	1.55	0.19	0.64
S08	1.1	1.67	0.39	25	19.4	1.31	0.14	0.15
S09	0.9	1	0.30	20	15.4	1.61	0.27	0.24
S10	3.3	0.5	0.21	20	15.4	1.14	0.14	0.48

3.2. Automated approach

3.2.1. Model 1

Model 1 is developed using the proposed automated approach, adopting the same pipe layout presented in Figure 2 to enable comparison with the conventional method. The initial Revit model is established with a uniform pipe diameter of DN 20 across the entire network. Dynamo serves as an intermediary tool to enable efficient data exchange and transformation between Revit and Excel. The extracted parameters from the Revit model include segment identifiers, pipe diameters, plumbing fixture units, segment lengths, as well as the quantity and types of sanitary fixtures. The Dynamo workflow used for parameter extraction is illustrated in Figure 3.

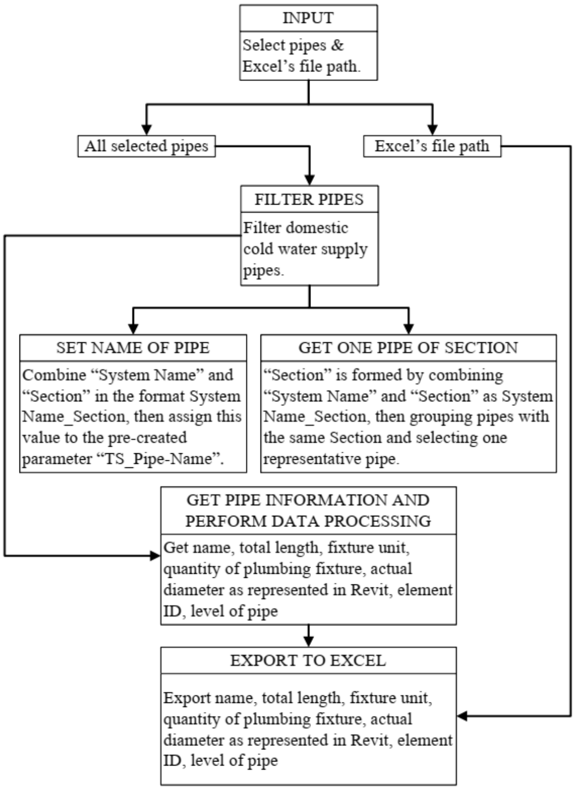

Figure 3. Exports data from Revit to Excel.

Once imported into Excel, the hydraulic calculation is executed automatically via embedded VBA. This approach overcomes a key limitation of the conventional method by automatically detecting data rows and dynamically inserting formulas, eliminating the need for manual setup. Furthermore, the VBA module utilizes iterative algorithms for pipe diameter selection based on maximum velocity criteria. Segments failing to meet design requirements such as those where the Revit diameter is smaller than the calculated value are automatically marked, allowing the designer to quickly identify and rectify non-compliant segments.

Subsequently, key parameters, including the design flow rate, calculated pipe diameter, and hydraulic gradient, are transferred back to the Revit model. This synchronization mechanism is implemented by matching unique pipe name attributes between the Excel environment and the Revit database. This update procedure ensures absolute consistency between the computed analytical data and the BIM model, establishing the foundation for subsequent automated model adjustments performed through Dynamo. Figure 4 illustrates the Dynamo workflow utilized to re-import these calculated values back into the Revit environment.

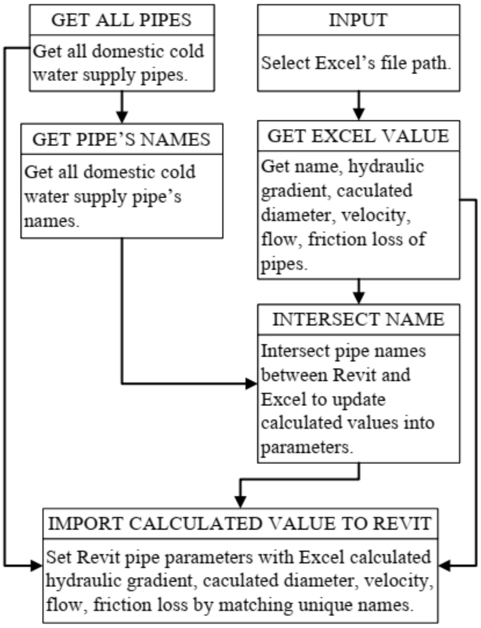

Figure 4. Imports calculated values from Excel to Revit.

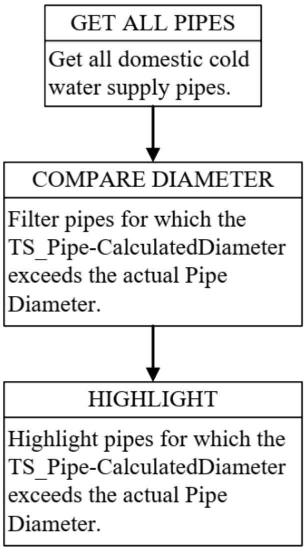

Figure 5. Check pipes diameter.

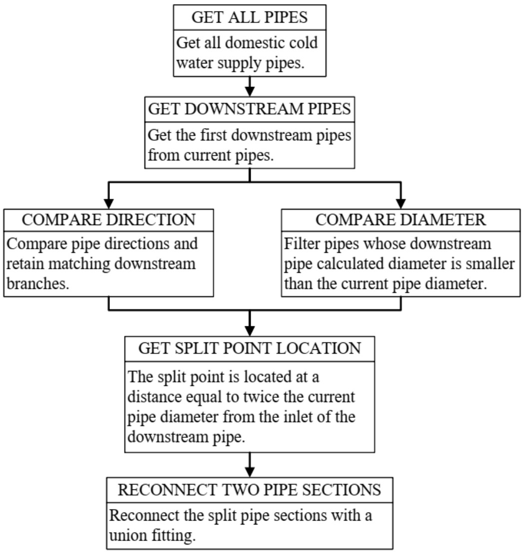

Figure 6. Split pipes.

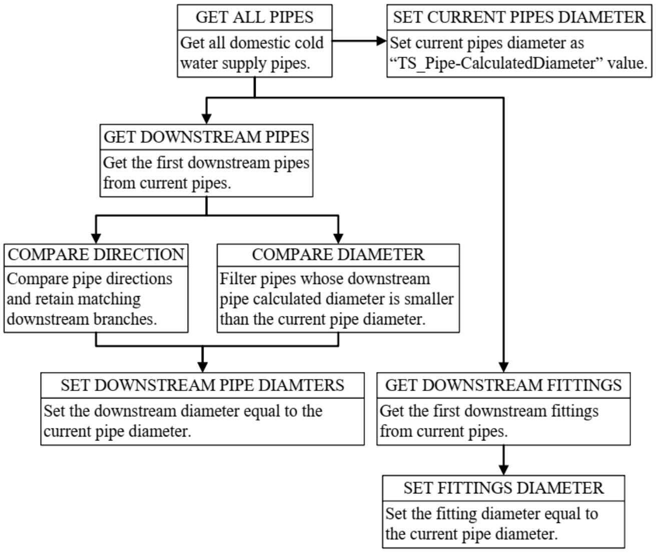

Figure 7. Pipe diameter update.

The system compares the initial pipe diameter against the calculated requirement. Any segments failing to satisfy the design criteria are marked, as illustrated in Figure 5.

After the data have been imported into Revit, Dynamo is employed to automate the model adjustment process. This stage consists of two main steps: pipe segmentation and pipe diameter modification according to the calculated design, as illustrated in Figures 6 and 7. Subsequently, the diameters of the pipe fittings and pipe segments are updated as in Figure 8 according to the calculated values to ensure consistency with the hydraulic design results.

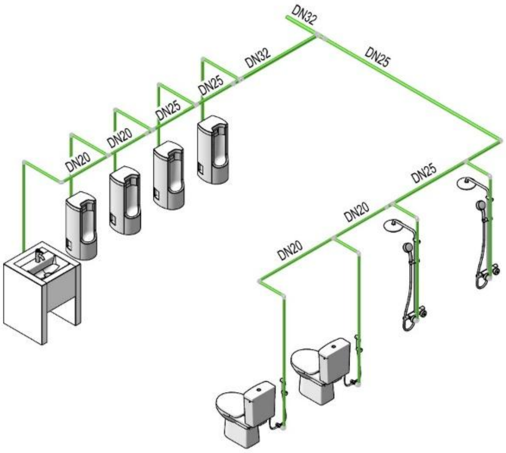

Figure 8. Results using the automated method.

3.2.2. *Model 2*

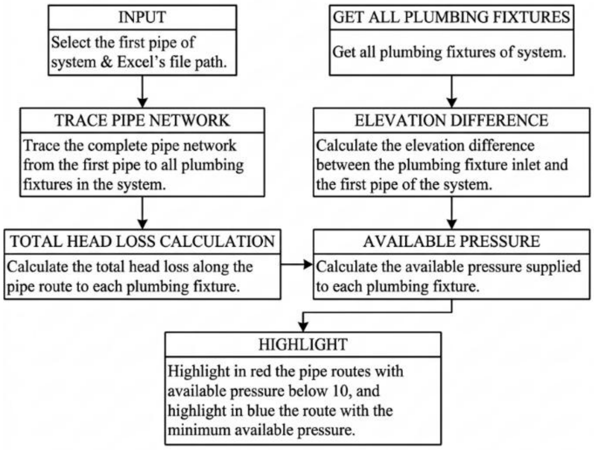

Figure 9. Most hydraulical.

Model 2 is developed to demonstrate the capability of the proposed framework to identify the most critical hydraulic path within the water supply system. The critical hydraulic path is defined as the pipe route for which the residual hydrostatic pressure at the plumbing fixture inlet is lower than 10 m, in accordance with the Vietnamese National Plumbing Code [19].

The process begins with selecting the first pipe segment of the system and the Excel file for data storage. Subsequently, all pipe routes leading to the plumbing fixtures are traced. The head loss of each individual pipe segment is calculated and then accumulated to determine the total head loss along each route. Based on these results, the residual pressure at the inlet of each plumbing fixture is evaluated. The route with the minimum residual pressure is highlighted in green, and the routes with residual pressure below 10 m are highlighted in red. The calculated residual pressure values are then assigned to the comment parameter of the corresponding plumbing fixtures. Finally, all calculated results are exported to Excel for further analysis and verification.

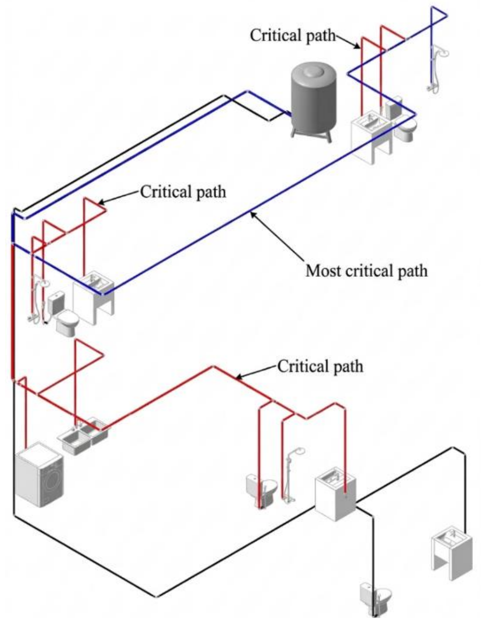

Figure 10. The most hydraulically adverse pipe route.

3.2.3. *Model 3*

While Models 1 and 2 demonstrated the performance of the automated algorithms on a localized restroom layout, Model 3 extends the application to a proper high-rise water supply network. This model integrates the procedures from both previous segments to evaluate the tool's performance on a larger scale.

As illustrated in Figure 11 and 12, the integrated toolkit can handle the large volume of data inherent in high-rise projects. It significantly reduces the manual calculation burden, eliminates the need for repetitive data entry, and maintains strict model consistency, confirming its practical applicability for complex MEP designs.

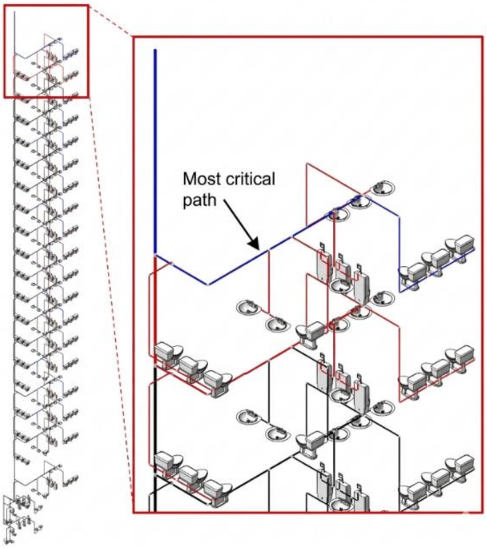

Figure 11. High-rise water supply network model.

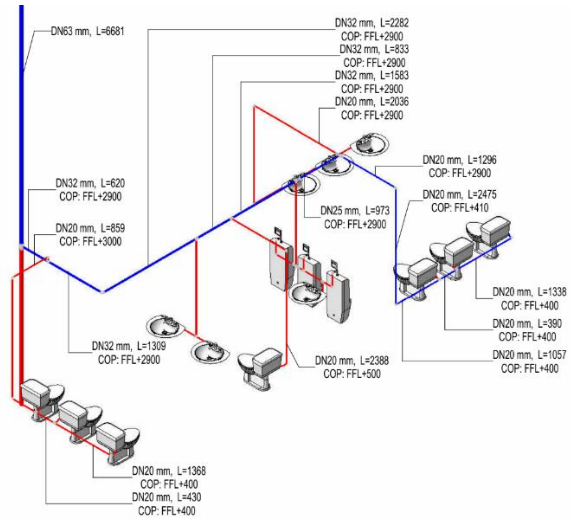

Figure 12. Designed pipe of the highest floor in Model 3 proposed by this study.

4. Conclusions

This study successfully developed an automated water supply design solution integrating Revit, Dynamo, and Excel in accordance with TCVN 4513:1988, enabling automatic data extraction, hydraulic computation, and synchronization within the BIM model. The results indicate that the integrated toolkit optimizes pipe diameter selection while overcoming the limitations of both the conventional manual approach and Revit's native calculation tools. Beyond automating pipe segmentation and facilitating transparent verification of computational results, the system supports report generation and enhances hydraulic visualization directly within the Revit environment, allowing users to efficiently assess system performance and identify hydraulically adverse pipe routes throughout the network.

Acknowledgements

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Data availability

The source code of the integrated application developed for this study is available from the corresponding author upon reasonable request.

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